PATENT SPECIFICATION

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COMPLETE SPECIFICATION.

Improvements in and relating to Coil Windings for Dynamo-electric Machines.

We, THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, a British company having its registered office at Crown House, Aldwych, London, W.C. 2 (Assignees of IVAN HARRY SUMMERS, of 124, Green Street, Lynn, County of Essex, State of Massachusetts, United States of America, a citizen of the United States of America), do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to coil windings and more particularly to the windings of alternating current dynamo-electric machines.

In large alternating current generators in which the windings, which are disposed in the armature slots, consist of conductors of considerable depth, the magnetic flux across the slots, due to the current in the conductors, gives rise to parasitic voltages within the conductors which induce eddy currents therein. These currents if of sufficient magnitude may produce objectional heating of the winding and cause the material of the conductor to be inefficiently utilized.

In such a machine, where each armature slot is filled with several conductors arranged one above the other, the flux due to current carried by the bottom conductor has a path partly through the iron core and partly through the space between the side walls of the slot. The distribution of this flux for convenience may be regarded as uniform from the top of the conductor to the mouth of the slot. Likewise, the flux due to current carried by the second conductor from the bottom may also be regarded as evenly distributed in the space between the slot walls from the top of that conductor to the mouth of the slot and similarly for the remaining conductors in the slot. The total flux density in the slot, therefore, is not uniform, but increases from the top of the bottom conductor to the mouth of the slot. In the above, consideration has been given only to the flux between the top of a conductor and the mouth of the slot. The current in each conductor produces a flux throughout the depth of the conductor which flux increases from the bottom to the top of the conductor and produces a voltage in the conductor which increases from the bottom of the conductor to the top thereof in approximately a parabolic manner. The total voltage in any half turn of a coil is thus made up of a voltage due to the flux of that half turn of the coil plus the voltage due to the flux from the other half turns of the coil below the one in question. This voltage varies in magnitude for each half turn, being greatest for that half turn at the top of the slot. The parasitic voltages induced in the two sides of a machine wound coil are inverted relative to each other due to the fact that the reversing end turn of the winding inverts one side of the coil relative to the other side. As a result of this reversal, the difference of the voltages induced in the top and the bottom portions of a conductor in one side of the coil is partly neutralized by that in the other side of the coil. But because of the unequal distribution of flux throughout the depth of the slot, as pointed out above, there still remains a voltage difference between the top and the bottom portions of the conductor which gives rise to objectional eddy currents through the conductor forming the winding.

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The parabolic distribution of voltage in the half turns of a coil referred to can be resolved into an elementary parabolic component and a linear component having a slope of an order corresponding to the number of conductors in the slot below the one in question. The arrangement of strands in accordance with this invention does not purport to completely balance the parabolic elements, since, even when those of opposite sense are balanced, a small remaining unequal voltage distribution will remain. It is possible, however, to balance the linear elements so completely that the remaining eddy current losses will be reduced to a negligible amount. An object of this invention, therefore, is the provision of an improved multi-turn winding in which the eddy current losses in the conductor are reduced to a relatively low value.

In connection with the above explanation, reference is made to the article entitled, "Eddy Currents in Stator Windings" by H. W. Taylor in "The Journal of the Institution of Electrical Engineers" (London) for April 1920, Vol. 58.

Our invention will be better understood from the following description taken in connection with the accompanying drawing.

In the accompanying drawing, Fig. 1 represents a two-turn coil according to this invention; Fig. 2 is a cross section on line 2—2 of Fig. 1, showing the sides of the coil in their respective armature slots; Figs. 3 and 4 are representations, showing an arrangement for a three-turn coil corresponding respectively with Figs. 1 and 2 for the two-turn coil, and Fig. 5 is a section on line AB of Fig. 3.

In Fig. 1, we have illustrated a two-turn form-wound coil 1 which has at each end thereof the usual reversing end turns 2. The conductor 3, of which the coil is formed, comprises four double strands forming four layers or laminations, the strands being made double to better facilitate the edgewise bending thereof. The strands are separately insulated throughout their length, except, of course, at the terminals 4 and 5 where suitable solid connections are made with adjacent coils, the several strands of the conductor of each coil forming so many separate parallel circuits. In a two-turn coil, as shown for example by Fig. 1, we give the conductor a twist, 6, of 180° in each turn of the coil at the rear end or end opposite the connection end of the coil. The effect of this 180° twist will be more clearly seen by referring to Fig. 2. Here the two sides of the coil are shown in their respective slots 7 and 8, which are spaced apart in the armature either a full pole pitch, or approximately so, according to whether the winding has a full or a fractional pitch. Here for convenience in following the reversals of the conductor due to the end turns 2 and the twists 6, we have shown the conductor having one double strand shaded. The slots 7 and 8 are four conductors deep, the four conductor positions in the slot being designated as positions 1, 2, 3 and 4. The linear component of the parasitic voltage affecting the conductor in position 1, being at the bottom of the slot, will be taken as 0, and, since each conductor is affected by the flux of the conductors below it, as explained above, the corresponding voltages of the conductors in positions 2, 3 and 4 will have values proportional respectively to 1, 2 and 3. For the same reason that the parasitic voltage induced in the conductor in position 2 is greater than that induced in the conductor in position 1, the top strand of each conductor is subjected to a greater parasitic voltage than the bottom strand thereof. Because of the fact that the flux increases in density from the bottom of the slot to its mouth, as already explained, the reversal of the conductor due to its passing around the usual reversing end turn is not alone sufficient to equalize in the two sides of the coil the voltage difference produced in the top and the bottom strands of the conductor. We therefore give the conductor the 180° twist, 6, in each turn of the coil.

Referring to Fig. 2, we shall call the direction of the parasitic voltage induced in the conductor positive, when the shaded strand is at the top, and when the shaded portion is at the bottom of the conductor, we shall call the direction of the induced parasitic voltage negative. Starting with the conductor in the bottom slot 7 and adding up the voltages induced in the half turns of a single coil, we have plus 0, plus 3, minus 1, and minus 2 which equals 0. It will thus be seen that by this arrangement we have eliminated any tendency toward circulating currents in the coil due to the linear components of induced parasitic voltage and that the ends, therefore, may be solidly clipped together without the usual resulting disadvantages of excessive heating due to eddy current losses.

In Figs. 3, 4 and 5 we have shown an arrangement for a three-turn coil. The coil 10 in this case is shown having the usual reversing end turns 12. The conductor 13, of which the coil is formed, comprises, as before, four double strands,

each insulated and forming four layers or laminations. The various strands comprising the conductor are solidly connected together in parallel at the terminals 14 and 15. In this case we have shown the conductor having but a single twist 16 located at the front or connection end of the coil substantially a whole turn distant from terminal 14. The effect of this twist is clearly seen by reference to Fig. 5, which is a section on line A B. Fig. 3.

The sides of the coil are shown in Fig. 4 occupying slots 17 and 18 just as in Fig. 2. The slots in this case, however, are shown of sufficient depth to receive six conductors instead of four. The six conductor positions are designated by numbers 1 to 6 inclusive, and given voltage values as before. Starting with the conductor in the bottom of slot 17 and adding up the linear voltages induced in the half turns of the single coil, we have minus 0, plus 5, plus 1, minus 4, plus 2, minus 3, which equals plus 1. In this case the resultant has not been reduced to 0 but the value has been so far reduced that it has little effect. Without the twist we have put in the coil, this resultant would have been 9, so that by our insertion we have reduced the linear voltage to 1/9, and the losses therefore to 1/81, in this case. For coils having a greater number of turns, a similar arrangement may be made use of, wherein the conductor is twisted one or more times in its several turns at the ends of the coil. In case it is not thought best to seek perfect immunity from eddy currents, but merely to reduce them by a large percentage, we prefer to place but a single twist in one coil turn at the connection end of a multi-turn coil as illustrated in Fig. 3. It is evident from a study of the usual form coil winding that the most convenient place to make this twist is at this point, for by placing it there only one turn need be unwound, twisted and rewound; and furthermore, the twist is at the top of the coil, where it will least interfere with the binding bands that resist short circuit stresses. The reduction by this single twist is not great enough to be satisfactory in two turn coils, and so in this case, at least, it is desirable to introduce two twists as shown in Fig. 1. For six-, seven- and eight-turn coils, the percentage of reduction of losses is not very great, but in those cases the circulating current loss is so small, due to the relatively large number of turns in the coil, that it is not necessary in these cases to obtain any greater reduction.

With the twist only in the top conductor on the connection end of the coil, the circulating current loss, due to the linear parasitic voltages in coils with different numbers of turns, will be reduced in the following proportions:

Number of Turns in Coil	Number of Unbalanced Units of Circulating Voltage		Ratio of Circulating Current Loss in Twisted Coil to Loss in Std. Coil.
	Standard Coil	Twisted Coil	
2	4	2	.250
3	9	1	.012
4	16	2	.016
5	25	7	.078
6	36	14	.151
7	49	23	.221
8	64	34	.281

In cases where the space available on the connection end is limited, it may be preferable to place the twist at the back end of the coil at the end of the bottom conductor on the top coil side. This position of the twist gives less reduction of loss than the twist in the connection end above mentioned, but occurs in a place where there is more space available.

In the figures of the drawing the conductor terminals 4 and 14 are shown in the bottom of the slots. Evidently, it will be equally possible to have them enter the tops of the slots. This is not ordinarily done, however, as it brings the terminals to the air gap side of the winding where the available space is very limited, unless the coil is fanned out at a considerable angle. However, where this fanning out is not objectionable, this conductor may be placed in the top of the slot, and consequently, the desired point of twist will then be transferred to the back end of the coil at the end of

the first half turn, instead of being on the connection end, a whole turn distance from the terminal.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A multi-turn coil for a dynamo-electric machine, having reversing end turns comprising a conductor formed of a plurality of insulated strands, the conductor having a twist of 180° in one of the end turns of the coil.

2. An armature coil having reversing end turns comprising a plurality of turns of a conductor formed of insulated strands, the conductor being twisted in one of the end turns of the coil to maintain the order of the strands in the two sides of that turn of the coil unreversed.

3. A multi-turn coil for a dynamo-electric machine, having reversing end turns comprising a conductor formed of a plurality of insulated strands, the conductor of the coil having a twist of 180° in the upper turn at one end of the coil.

4. A form wound armature coil comprising a plurality of turns of a conductor formed of insulated strands, the upper turn of the coil at its connection end having a twist of 180°.

Dated this 23rd day of December, 1926.

JOHN GRAY,
Crown House, Aldwych, London, W.C. 2,
Agent for the Applicants.

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[This Drawing is a reproduction of the Original on a reduced scale]

Fig. 1.

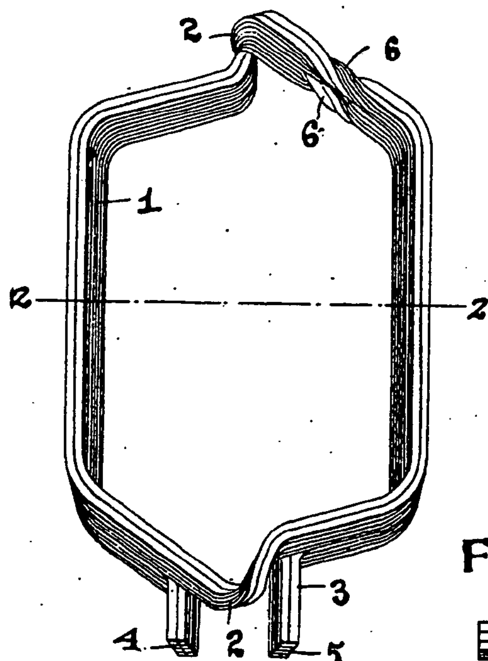


Fig. 2.

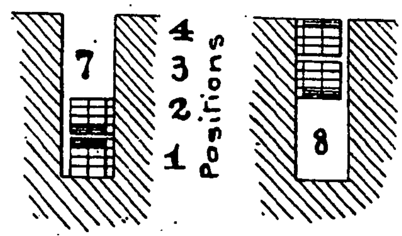


Fig. 5.

Fig. 3.

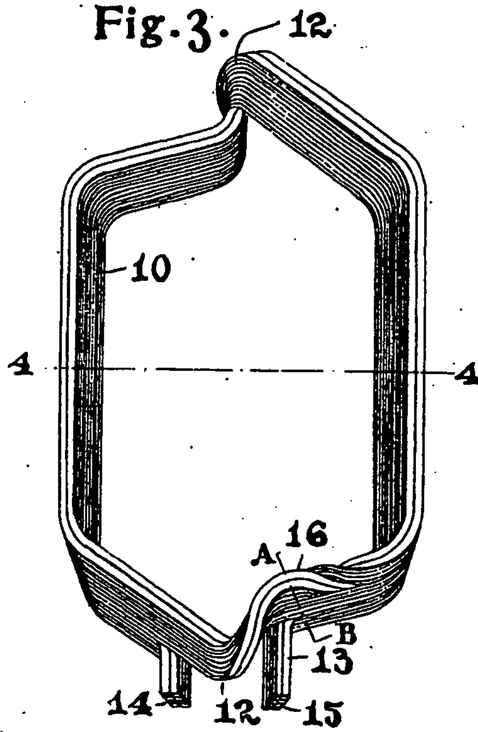
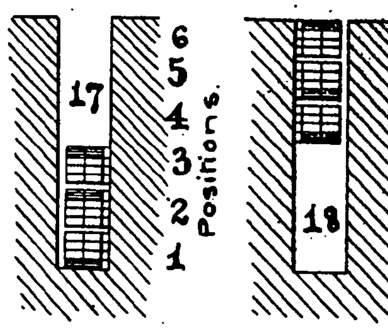


Fig. 4.



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